ACCELERATED KILN SCHEDULES

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

ACCELERATED KILN SCHEDULES[1]

By

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Very great advancements in the field of the kiln drying of wood have been made in the last 10 years. These advancements include increased understanding and operation of the machine used, the dry kiln; a great increase in the number of properly trained kiln operators, with authority to use their special knowledge; and the development of new, economically sound kiln schedules. During World War II the Forest Products Laboratory had a number of crews in the field testing dry kilns to certify them for use in drying lumber under the temperature requirements of Army-Navy specifications. These crews found very few kilns that actually met the requirements. But with electrical measuring instruments it was comparatively simple to make slight modifications so that the kilns could attain the uniform conditions required by the specifications. After the war, the Laboratory undertook a program of training kiln operators in a series of demonstrations. These were held both at the Laboratory and in the field, with three being held in the New England area. As a result of these demonstrations, more than 700 persons have been trained in kiln operation.

It is the third phase of the major advance in the field of kiln drying that is the subject of this paper, the new Forest Products Laboratory schedules for the kiln drying of wood that permit kiln operators to accelerate drying without the hazard of excessive seasoning defects.

In February the new Forest Products Laboratory schedules for kiln-drying of wood were published.[3] These schedules and a full explanation of them also have been published in one of the trade journals.[4] The schedules were compiled by O. W. Torgeson from all the information collected at the Forest Products Laboratory on this subject during the past 14 years This information includes experience with the previous schedules published in 1937, results of intensive research on schedules for individual woods, studies of the stresses that develop in wood as it dries, and an analysis of the most advanced schedules that were being used in industry. The new schedules incorporate the principles of acceleration enunciated by R. C. Rietz.[5]

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[1] Paper presented at Vermont Wood Products Conference, Northfield, Vt., May 24, 1951.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Torgeson, O. W., Schedules for the Kiln Drying of Wood. Forest Products Laboratory Report D1791. February 1951.

[4] Torgeson, O. W., New Schedules for Kiln Drying Wood (Chicago) April 1951.

[5] Rietz, R. C., Accelerating the Kiln Drying of Hardwoods. Southern Lumberman, July 1, 1950

A kiln schedule is a guide to the proper temperature and relative humidity conditions to use in the drying of a particular kind of wood. It shows starting conditions and when changes in these conditions can be made without degrading the stock. Its objective is to produce a satisfactory drying rate without causing objectionable drying defects. The major factor in accelerating drying by using a kiln is the heating of the wood to temperatures higher than can be maintained outdoors. When air is heated, its relative humidity goes down. When relative humidity is lowered, the wood of many species is likely to check. Therefore, it is necessary at the start of kiln drying to retain the humidity in the air by closing the vents, or to add humidity by a steam spray. As drying goes on, it is necessary to change the kiln conditions to maintain a fast drying rate. Changes may consist of raising the temperature, lowering the relative humidity, or both. A drying schedule is a guide as to when these changes can be made without causing defects. Many people are familiar with the old schedules given in the Forest Products Laboratory Technical Note 175. They have been used as a basis for kiln schedules all over the world. These old schedules call for making temperature and relative humidity changes at the same time. All call for holding the first conditions until the stock is down to 40 percent moisture content or less before making any change. Figure 1 shows old schedule 7 as used for 4/4 northern red oak. The schedule started with a dry-bulb temperature of 110° F., a wet-bulb temperature of 105° F., and a relative humidity of 85 percent. No change was made until the stock dried to 40 percent moisture content. At that time small changes were made in both temperature and relative humidity. Subsequent small changes were made at 30, 25, 20, 15, and 10 percent moisture content. This particular kiln run of oak started at about 70 percent moisture content and took about 744 hours, or 31 days, to dry to 7 percent, not including conditioning treatment to remove case-hardening. A typical long-drawn-out drying curve resulted.

Other previously published drying schedules familiar to many people are those in which the wet-bulb temperature set up for the initial conditions is held constant throughout most of the run. Increases in dry-bulb temperature have the secondary effect of reducing relative humidity. There is a real danger in attempting to modify this type of schedule to accelerate drying. This hazard is discussed later on in this article.

Figure 2 shows the general pattern of the Laboratory's new schedules with an initial period of degrade control, an intermediate period of accelerated drying, and a final period of quality control. Low temperatures must be used to start with for hardwoods, and they must be maintained until there is no more free water (water above the fiber-saturation point) at any location in the wood. This means the average moisture content must be around 20 percent or below. Low temperatures ordinarily are not necessary for softwoods. The humidity must be high at the start, during the period of degrade control, but lowering of the relative humidity can be started long before the temperature can safely be raised. Thus, lowering of the relative humidity is the first accelerator. With woods of very high moisture content, lowering of relative humidity can start fairly early or at fairly high moisture-content values. This is not true for dense woods that normally have a low initial moisture-content value. Thus, the relative-humidity pattern does not coincide at all with the temperature pattern, and there is a real need for humidity schedules

separate from the temperature schedules. Figure 3 shows, in condensed form, the entire scheme of the new Forest Products Laboratory schedules for the kiln drying of wood. The upper part of figure 3 shows the temperature schedules, and the lower part the humidity schedules.

Which of these schedules to use for a specific item is given in the index of Forest Products Laboratory Report No. D1791. Schedules for hardwoods are listed in one table, and schedules for softwoods are listed in another table. Schedules listed for special items, such as dimension stock and squares, may be different from the schedules for lumber of the same species because of differences in seasoning characteristics and differences in use requirements.

There are 14 different temperature schedules, ranging from T1, at very low temperatures for color control, to T14, with high temperatures for use with southern pine, true firs, and other easy-drying softwoods. Some pairs of the schedules are identical except for the final temperatures. For instance, T3 and T4 both start with 110° F., and succeeding steps are 120°, 130°, and 140° F. In T4, used for northern red oak 4/4 stock, the final temperature is 180° F. T3, with final temperature of 160° F., is recommended for 8/4 northern red oak. Experiments have shown that the slightly lower final temperature is safer from the standpoint of honeycomb checks. Other schedule pairs are schedules 5 and 6, 7 and 8, 9 and 10. Schedules 11, 12, 13, and 14 are each distinct. All temperature schedules call for making the first change in temperature at 30 percent moisture content, the second at 25 percent moisture content, the third at 20 percent moisture content, and the last at 15 percent moisture content. There are only five temperature steps.

The lower part of figure 3 shows the humidity schedules. In Report No. D1791 there are six classes of humidity schedules depending upon original green moisture content. In figure 3 all six classes have been condensed into one table. This figure shows that the scheme of lowering the wet-bulb depression is the same in each of the six separate classes. Classes A, B, C, D, E, and F differ from each other only by the initial moisture-content values and the values at which changes in relative humidity are made. For schedule A the first change is made at 30 percent, for schedule F the first change is made at 70 percent, and for the other schedules the changes grade in between these values. One of the biggest advantages in the new schedules is the making of the first change in relative humidity when the wood loses about one-third of its green moisture content. The D humidity schedules, for example, are for woods having green moisture-content values between 80 and 100 percent. In this class are the humidity schedules recommended for northern red oak. The first change in relative humidity comes at 50 percent moisture content, a second change is made at 40 percent moisture content, and other changes at 35, 30, and 25 percent.

Each class of humidity schedules consists of eight sets of wet-bulb depressions. For instance, D1, D2, D3, D4, and so on. The initial condition called for by D2 is a wet-bulb depression of 4° F. Showing humidity in terms of wet-bulb depression is another way the new schedules differ from the old. In the old schedules both the dry-bulb temperature and the wet-bulb temperature were given. In the new humidity schedules it would not be possible to give actual wet-bulb temperatures because the humidities are used with different combinations of dry-bulb temperatures. The most practical way to express humidities in schedules of this type is to use the wet-bulb depressions.

Returning to humidity schedule D2, the first condition is a 4° F. wet-bulb depression. That is held until the kiln samples come to a moisture content of 50 percent. Then it is changed to a 5° F. wet-bulb depression. At a moisture content of 40 percent, it goes to an 8° F. depression, and so on to a 14° F. depression, a 30° F. depression, and finally a 50° F. depression.

The second important advantage of the new schedules is the dropping of the intermediate relative-humidity values much more rapidly than in the old schedules. Referring back to the temperature schedules, the use of higher final temperatures than were previously used in the old schedules for many woods is the third major change in the new schedules. In addition to these three major changes, the initial relative humidities have been adjusted for some refractory woods to prevent surface checking at the start of drying. Now that better kiln equipment in use throughout the country is tuned up in better condition and operated by better kiln operators, the conditions that our research results show are necessary for some of the more refractory woods can actually be prescribed.

The new schedules are not as complicated as they appear at first glance. The easiest way to use them is to write down on a sheet of paper or a form, such as used in table 1, the information needed for any particular wood. In the index, in the back of Report No. D1791, the schedule recommended for 4/4 northern red oak is T4-D2. There are six steps in jotting down a working schedule such as T4-D2 for red oak or any other wood. The first step is writing down the humidity step numbers 1, 2, 3, 4, 5, and 6, beginning at the top of the form. Opposite them, in the "Moisture content" column, put down the moisture-content values given for these steps in the D schedules. Then fill in the wet-bulb depression humidity schedule from D2. The next step is to put down the temperature steps in the proper column. Put a "1" opposite the moisture content from 35 to 30, and fill in with "1's" to the top of the table. Then, from the lowest number "1", go on down "2", "3", "4", and "5". Then, in the "Dry-bulb temperature" column, put 110° every place where there is a number "1" in the temperature-step number column, and opposite number "2" put 120°, and so on down, 130°, 140°, 160°, filling in the dry-bulb temperatures for temperature schedule T4. Humidity step 6 can be repeated if needed. The last step, in order to get a schedule for use with regular kiln-operating instruments having dry-bulb temperature and wet-bulb temperature pointers, is to subtract the wet-bulb depressions from the dry-bulb temperatures and fill in the wet-bulb temperature column. The last two columns of "Relative humidity" and "Equilibrium moisture content" can be filled in from the table of such values reproduced in Report No. D1791.

The kiln schedules are based on the moisture content of the stock. The use of adequate kiln samples is the best method to follow the moisture condition through the entire kiln-drying process. The moisture content of green wood varies greatly between species. There are some differences in moisture content between heartwood and sapwood of almost any hardwood, while in the softwoods the moisture content of the sapwood is much greater than that of the heartwood. Because of these and other variables a number of representative samples are necessary. At least one should be used in each truckload on each side of the kiln, and not less than six in each kiln charge. The average moisture content

of the wettest one-half of the total number of samples should be used to govern the changes in kiln conditions. The schedules are set up on the moisture content of heartwood. Heartwood usually takes longer to dry than sapwood and is more susceptible to seasoning defects.

Figure 4 shows the new schedule for the kiln drying of 4/4 northern red oak in the graphical form. This is made up from the results of the kiln drying of two charges of red oak in the Forest Products Laboratory's semicommercial kilns in the kiln-drying demonstration last February. The initial temperature is 110° F. and that temperature is held until an average moisture content of 30 percent is attained by the wettest half of the kiln samples. Reduction of relative humidity is started at an average moisture content of 50 percent. Another drop is made when the average moisture content of the wettest half of the samples gets to 40 percent. The second drop is of greater magnitude than the first. At 35 percent moisture content the relative humidity is dropped still more, and so on, until at 25 percent moisture content the relative humidity is 10 percent. This is quite different from the old schedule for oak. An equilibrium moisture content of 2 percent on the surface furnishes a greater incentive for the moisture to move from the insideto the outside of the piece. Temperature gradually steps up, starting at 30 percent moisture content. At 15 percent it goes to a maximum of 180° F.

If the wet-bulb temperature were held constant and the same scheme of relative-humidity lowering were obtained by raising dry-bulb temperature, there would be danger of causing serious internal checking, because high temperatures would be used before the wood in the cores of the pieces would be down below the fiber saturation point. Prolonged heating of wet wood at high temperatures weakens it greatly, so that when maximum internal tension stresses develop during the last stages of drying, the wood no longer is strong enough to resist them.

Drying, to the point of equalizing and conditioning, in the two oak runs combined in figure 4, took 26 days. By the old schedule it took 31 days. The runs with the new schedule were started at a much higher moisture-content value, 87 percent. The present schedule would dry partially air-dried oak (70 percent moisture content) in 21 days. The difference between 31 days and 21 days is a saving of one-third the drying time. In some instances it may be possible to cut drying time for oak still further; but for the time being schedule T4-D2 is as far as the Laboratory will go in making general recommendations to the public for 4/4 northern red oak.

The Laboratory schedules will, in some cases, require modification; they cannot be used blindly, because of differences in the characteristics of the wood, in the local production and selling practices, in the degree of care in kiln operation, and in kiln characteristics. Modifications of the standard schedules should be based on careful observations of the stock during drying and on the quality of drying desired. It should be understood that there are some variations in seasoning characteristics within each species and that identical results cannot always be obtained. For some of the less refractory species more severe temperatures or relative humidities can be used to reduce drying time without causing excessive increases in the amount of checking. For instance, quarter-sawed material has less tendency to surface check than plain-sawed and, consequently, lower initial relative humidities can be used.

Without reliable information or data, however, radical departures from the standard schedules should not be made. Small changes can be made in successive steps, based upon close observations of the behavior of the stock in each run. The Laboratory has just recently learned that the schedule recommended for 4/4 cottonwood is satisfactory in a cross-circulation kiln. Also, that its schedules for 4/4 southern pine and Douglas-fir are satisfactory. In fact, for the pine and fir, an operator, whom the Laboratory trained in one of its kiln-drying demonstrations, was able to use a temperature schedule one number higher than prescribed in the index. This does not mean that the Laboratory is going to change its schedules for these woods, but it means that individual kiln operators should look for opportunities to modify these schedules and get faster drying without causing objectionable drying defects.

These schedules are intended primarily for use in compartment kilns with fast air circulation. Air velocities of 200 to 350 feet per minute through the load are quite common. When air velocities are much less than this, the initial wet-bulb depressions can be increased somewhat. For natural circulation kilns, the wet-bulb depressions can be increased as much as 4° F.

In a progressive kiln, the green end is usually operated at a rather low temperature and a high relative humidity as compared to the conditions at the dry end. In some progressive kilns, only the dry end is under temperature and humidity control. The initial and final conditions in these schedules can be used as a guide in selecting the proper conditions for the green and dry ends of the kiln. For refractory items, there would be a danger in using the schedules in this way because the intermediate conditions are likely to be more severe in the progressive kilns. In such cases, a somewhat more conservative temperature and relative-humidity schedule may be required, instead of the one recommended for compartment kilns.

In this paper an attempt has been made to cover thoroughly the general composition of the new Forest Products Laboratory schedules for the kiln drying of wood and to go through, as an example, the use of one schedule, T4-D2, for 4/4 northern red oak. The paper has touched briefly on some of the major considerations in schedule application as outlined in Forest Products Laboratory Report No. D1791. Other points covered by this report include need for accurate instruments and need for proper location of the control bulbs, final moisture-content requirements, and equalizing and conditioning treatments for uniformity of moisture content and case-hardening relief.

Copies of the new schedules can be obtained from the Forest Products Laboratory, Madison 5, Wis.

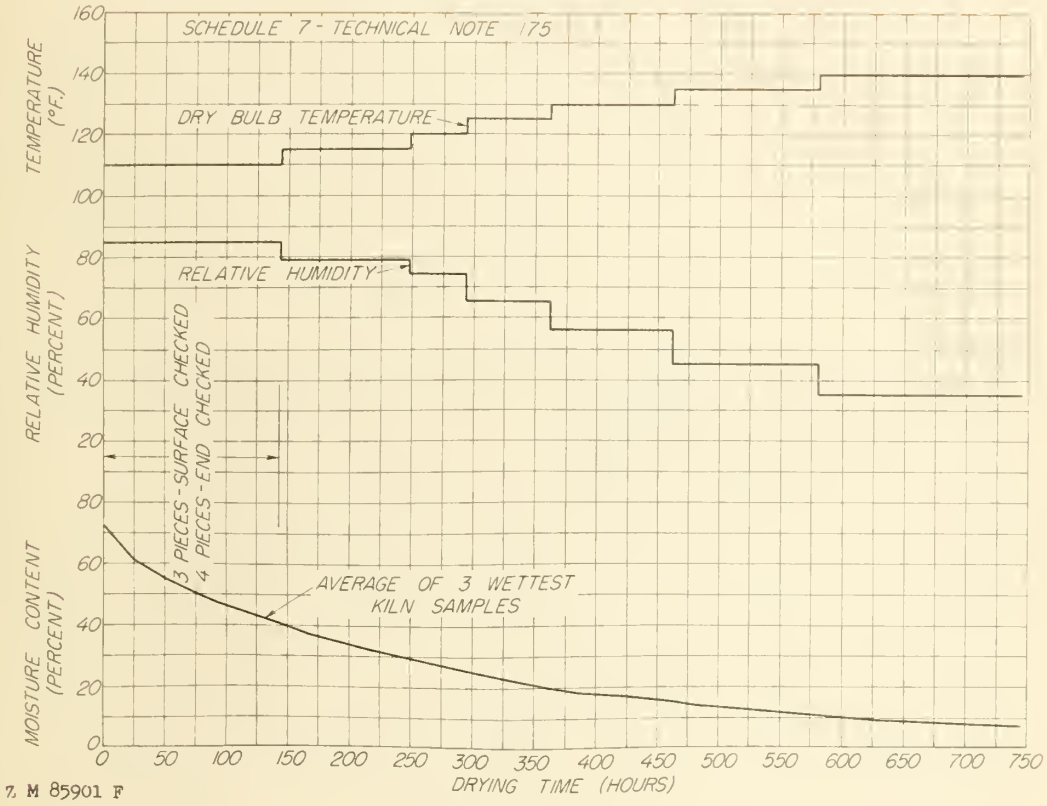
Table 1.--Combined temperature and humidity schedules for kiln drying green 4/4 red oak

Temperature step number	Humidity step number	Moisture content class D: Moisture content From	Moisture content class D: Moisture content To	Temperature schedule T4: Dry bulb	Humidity schedule 2: Wet-bulb depression	Humidity schedule 2: Wet bulb	Relative humidity[1]	Equilibrium moisture content[1]
		Percent	Percent	°F.	°F.	°F.	Percent	Percent
1	1	Initial	50	110	4	106	87	17.5
1	2	50	40	110	5	105	84	16.2
1	3	40	35	110	8	102	75	13.3
1	4	35	30	110	14	96	60	9.9
2	5	30	25	120	30	90	31	5.4
3	6	25	20	130	50	80	10	2.0
4	6	20	15	140	50	90	14	2.6
5	6	15	Final	180	50	130	26	3.3

[1] Relative-humidity and equilibrium-moisture-content values corresponding to the given dry-bulb temperatures and wet-bulb depressions are given in a chart in Forest Products Laboratory Report No. D1791. Equilibrium moisture content is that moisture content to which wood will come if exposed long enough to that particular set of conditions.

Figure 1.--Kiln conditions and drying curve, 4/4 northern red oak, using old Technical Note 175 schedule 7.

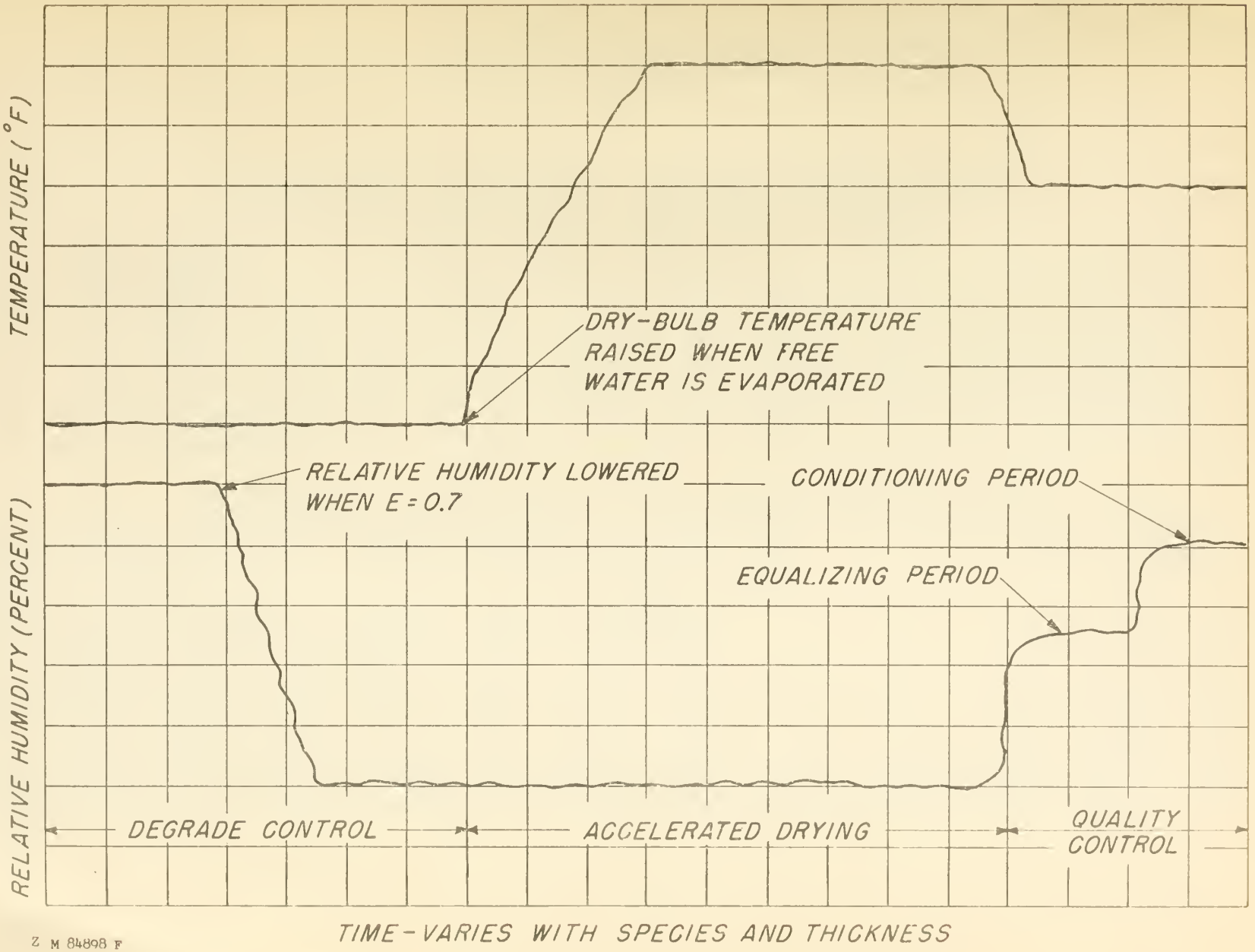
ZM 85901 F


SCHEDULE 7 - TECHNICAL NOTE 175
DRY BULB TEMPERATURE
RELATIVE HUMIDITY
3 PIECES - SURFACE CHECKED
4 PIECES - END CHECKED
AVERAGE OF 3 WETTEST KILN SAMPLES
TEMPERATURE (°F.)
RELATIVE HUMIDITY (PERCENT)
MOISTURE CONTENT (PERCENT)
DRYING TIME (HOURS)
160
140
120
100
80
60
40
20
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750

7. M 85901 F

Figure 2.--General pattern of new Forest Products Laboratory schedules for kiln drying of hardwoods.

ZM 84898 F


TEMPERATURE (°F)
RELATIVE HUMIDITY (PERCENT)
DRY-BULB TEMPERATURE RAISED WHEN FREE WATER IS EVAPORATED
RELATIVE HUMIDITY LOWERED WHEN E = 0.7
CONDITIONING PERIOD
EQUALIZING PERIOD
DEGRADE CONTROL
ACCELERATED DRYING
QUALITY CONTROL
TIME - VARIES WITH SPECIES AND THICKNESS

Z M 84898 F

Figure 3.--Forest Products Laboratory schedules for the kiln drying of wood (1951).

ZM 87228 F

TEMPERATURE SCHEDULES (DRY-BULB TEMPERATURES)

STEP NO.	MOISTURE CONTENT		TEMPERATURE SCHEDULE NUMBER												
	FROM	TO	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12	T-13	T-14
	%	%	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1	INITIAL	30	100	100	110	110	120	120	130	130	140	140	150	160	170	180
2	30	25	105	110	120	120	130	130	140	140	150	150	160	170	180	190
3	25	20	105	120	130	130	140	140	150	150	160	160	160	170	180	190
4	20	15	115	130	140	140	150	150	160	160	160	170	180	180	190	200
5	15	FINAL	120	150	160	180	160	180	160	180	160	180	180	180	190	200

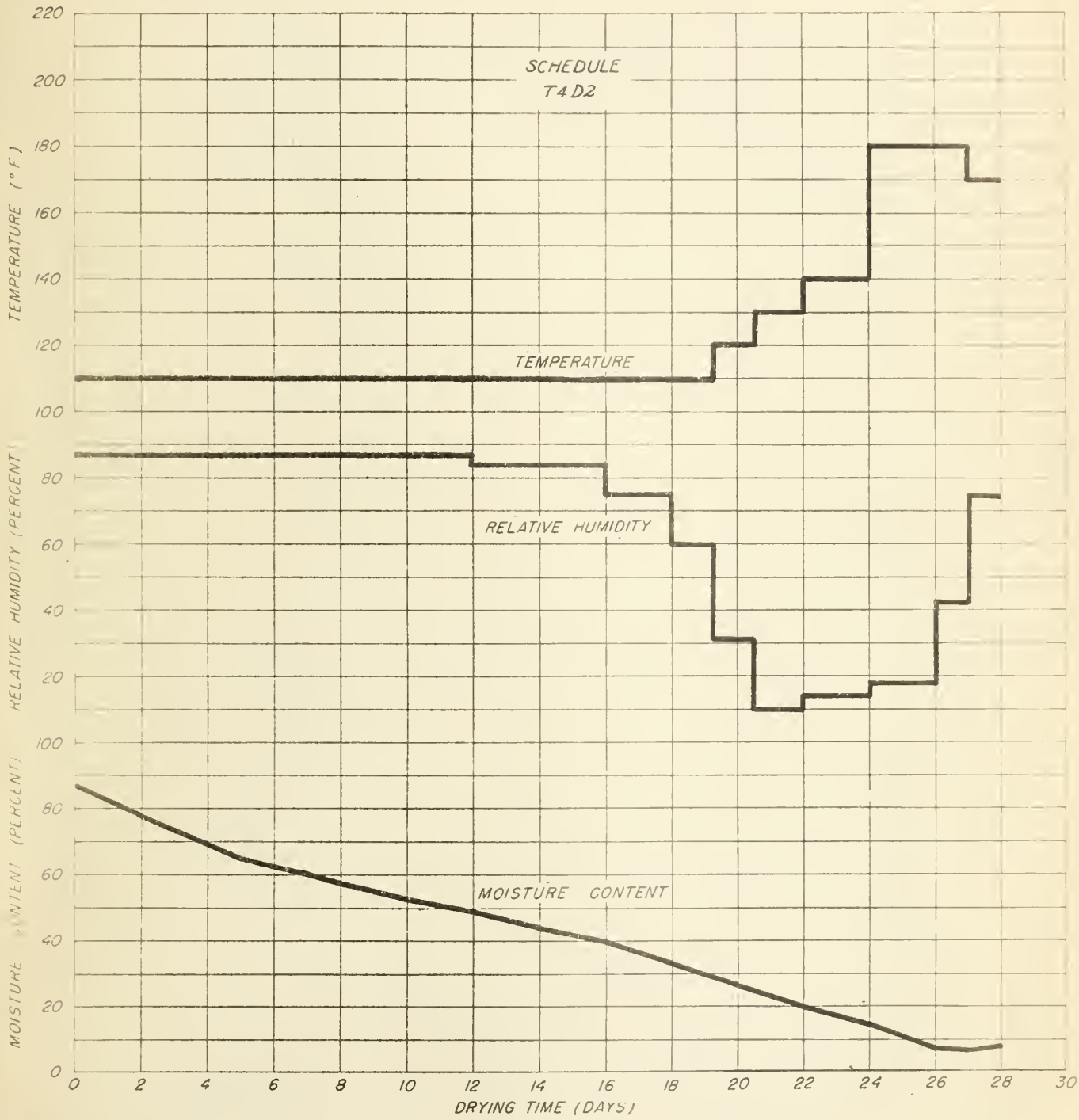
HUMIDITY SCHEDULES (WET-BULB DEPRESSIONS)

GREEN MOISTURE CONTENT CLASSES												STEP NO.	HUMIDITY SCHEDULE NUMBER							
BELOW 40%		40 - 60		60-80		80-100		100-120		ABOVE 120%			1	2	3	4	5	6	7	8
A		B		C		D		E		F										
MOISTURE CONTENT		MOISTURE CONTENT		MOISTURE CONTENT		MOISTURE CONTENT		MOISTURE CONTENT		MOISTURE CONTENT										
FROM	TO	FROM	TO	FROM	TO	FROM	TO	FROM	TO	FROM	TO									
%	%	%	%	%	%	%	%	%	%	%	%		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
INITIAL	30	INITIAL	35	INITIAL	40	INITIAL	50	INITIAL	60	INITIAL	70	1	3	4	5	7	10	15	20	25
30	25	35	30	40	35	50	40	60	50	70	60	2	4	5	7	10	14	20	30	35
25	20	30	25	35	30	40	35	50	40	60	50	3	6	8	11	15	20	30	40	50
20	15	25	20	30	25	35	30	40	35	50	40	4	10	14	19	25	35	50	50	50
15	10	20	15	25	20	30	25	35	30	40	35	5	25	30	35	40	50	50	50	50
10	FINAL	15	FINAL	20	FINAL	25	FINAL	30	FINAL	35	FINAL	6	50	50	50	50	50	50	50	50

Z M 87228 F

Figure 4.--Kiln conditions and drying curve 4/4 northern red oak, using new schedule T4-D2.

ZM 86987 F


SCHEDULE
T4 D2
TEMPERATURE
RELATIVE HUMIDITY
MOISTURE CONTENT
TEMPERATURE (°F)
RELATIVE HUMIDITY (PERCENT)
MOISTURE CONTENT (PERCENT)
DRYING TIME (DAYS)
220
200
180
160
140
120
100
80
60
40
20
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Z M 86987 F